CHONDRULES IN APOLLO 14 BRECCIAS AND ESTIMATION OF LUNAR SURFACE EXPOSURE AGES FROM GRAIN SIZE ANALYSES; Elbert A. King, John C. Butler and Max F. Carman, Dept. of Geology, Univ. of Houston, Houston, Texas, 77004.

Numerous spherical, subpherical and rounded bodies occur in at least three Apollo 14 breccia samples. Many of these objects are identical in texture, size and general mineralogy to common varieties of meteoritic chondrules. These lunar chondrules are not the relatively simple glass spherules that have been observed and described by many investigators in lunar samples from previous Apollo Missions, although some of the chondrules are partly glass and others are devitrified glass in part. The textures observed in lunar chondrules include spherical aggregates of mineral grains with indistinct margins; spherical brown glass chondrules enclosing euhedral olivine and/or pyroxene; spherical chondrules with pyroxene and plagioclase crystals that nucleate on the surface of the sphere and radiate into the interior of the chondrule with interstitial brown and turbid glass; and less perfectly spherical chondrules with basaltic, microbreccia and other fine-grained rock textures. The chondrules range in size from less than 0.1 mm. to more than 1.0 mm. Chondrules are abundant in samples 14313, 14318 and 14301 occupying more than 10% by volume of the observed portions of these samples. Rare to moderately abundant chondrules have been observed in samples 14305, 14306, 14311 and 14162. All of these samples contain numerous highly shocked mineral grains and rock fragments.

Why are chondrules present in Apollo 14 samples and are not recorded in the Apollo 11 or Apollo 12 samples? The major difference between the Apollo 14 and the Apollo 11 and 12 landing sites probably is that the Apollo 14 landing site is on the Fra Mauro Formation, believed to be mostly crater ejecta from the Imbrian event, and the Apollo 11 and 12 landing sites are on relatively undisturbed extrusive rocks that have not been involved in a large impact. Thus, we believe that the chondrules in the Apollo 14 samples may have been produced by the huge impact and accompanying phenomena that formed the Imbrian Basin. It does not appear that all of the chondrules have formed by the same mechanism. At least three different mechanisms may have formed chondrules in the Apollo 14 breccias: (1) Crystallization of shock-melted silicate droplets. This mechanism requires that pre-existing lunar rock, or a mixture of surface silicate materials, be melted by the energy of an impact, that the fluid silicate forms a roughly spherical shape due to surface tension, and that the silicate body subsequently crystallizes. The crystallization may have occurred after super-cooling, as has been experimentally demonstrated by Keil, Hanner and co-workers, or possibly more slowly as devitrification of a predominantly glass chondrule in fall back or base surge deposits that were at elevated temperatures; (2) Rounding of rock clasts in base surge deposits. The base surge deposits from the Imbrian event must have traveled across the lunar surface for as much as several hundred km. before final deposition. Abrasion and interaction of clasts and particles in the base surge may have produced consid-
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erable rounding of some rock fragments prior to deposition. This mechanism may have produced many of the multimineralic chondrules that seem to have igneous and microbreccia rock textures; (3) The inclusion of rock fragments and clasts in base surge and fall back deposits of greatly different bulk chemical composition may have caused rapid diffusion of cations between the surrounding deposit and the clasts, particularly if the deposits were initially hot. This mechanism is less certain and more speculative than the first two, but is the only process that occurs to the authors to explain the chondrules that appear to be clasts of dunite surrounded by fine-grained matrix in which there appear to be concentric diffusion halos around the clasts. Regardless of the exact mechanisms that form chondrules in Apollo 14 samples, the fact remains that at least three major types of chondrules are present in lunar samples and that these same types of chondrules are common in chondritic meteorites.

The suggestion that chondrules in the lunar samples are the result of processes accompanying large impacts leads to the possibility that at least some, perhaps many, meteoritic chondrules may have been formed by the same impact-related mechanisms. If some meteoric chondrules are produced in large impacts, this requires that at least one of the bodies involved in the event be a fair-sized planetary object, especially for mechanisms (2) and (3) to be valid. Where could these impacts have occurred? Probably the largest iron and silicate planetary body that ever existed in the Solar System was the proto-sun, the initial accumulation of matter at the center of the Solar System that was still accreting, but had not yet gained sufficient mass to become a star. Very large volumes of chondritic rocks may have been produced on the surface of the proto-sun by impacts of accreting objects, but the energy required to get pieces of this chondritic material away from the proto-sun into outer regions of the Solar System, distances of two or three AU and more, is extremely great. This mechanism not only requires very great energy, but also requires the movement of material away from the proto-sun early in Solar System history. This direction of movement probably would be contrary to the movement of most other Solar System debris at that time. However, the time that stellar activity was initiated in the Sun, perhaps some of the chondritic outermost surface could be propelled far away from the center of the Solar System in the same general direction of movement as much other Solar System debris. If the large impact hypothesis for the origin of chondrules is correct, chondrules and chondritic rocks may be an inescapable result of the terminal stages of accretion of all of the silicate-iron planets and large moons.

A total of 26 lunar fines samples (less than 1 mm.) has been sieved, and the grain size frequency distributions of the samples have been determined. These samples include three surface samples from Apollo 11, ten surface and trench samples from Apollo 12, and thirteen surface, trench and core tube samples from Apollo 14. In general, the grain size frequency distributions are characterized by very poor sorting, platykurtosis, and low values of skewness. Samples from Apollo 14 contain both the coarsest and the finest fines samples yet analyzed. A fines sample collected on the flank of Cone Crater is the coarsest sample with a graphic mean size of 112 microns. If only relatively undisturbed samples that were collected away from crater rims and coarse ejecta blankets are considered, the average graphic means of the Apollo
11, 12 and 14 fines samples are 63 microns, 69 microns and 49 microns respectively. Therefore, it seems probable that the graphic mean size (and other size distribution indices) correlate with the accepted ages of the assumed lunar surface material at different landing sites. Specifically, the graphic mean size of the surface regolith fines decreases with increasing meteoroid bombardment exposure age, as we have previously suggested. This relationship can be used to estimate the meteoroid bombardment exposure age of a surface site from size analysis information alone. This estimation requires that a number of samples are collected from relatively undisturbed sites away from coarse ejecta deposits. Furthermore, we find in the samples that we have analyzed that there is a tendency, in general, for surface samples to be finer than those from depth within the regolith. As we have reported previously, the size frequency distributions of many lunar fines samples are bimodal. The broad mode in the 1μ to 3μ size interval is due to the sticking together of finer particles by glassy spatter from nearby impacts, and the more narrowly defined mode near 5μ is due to the addition of finer particles, probably as secondary ejecta from the presumably older regolith surfaces of the lunar highlands. Using an approximately linear relationship between sample graphic mean size and age (which may not be justified) we estimate that there are regoliths in the southern lunar highlands with meteoroid bombardment exposure ages of approximately 4 billion years. Our estimated age for the Apollo 14 site is 3.7 billion years, and the youngest well-dated Apollo 14 rocks cluster around a value of 3.88 billion years (Wasserburg and co-workers). Our estimated age should approximate the Imbrian event, and the strontium-rubidium age should approximate the cooling of the last igneous rock prior to the Imbrian event, assuming that sampling is adequate.